

**A MACRO ROUTING TECHNIQUE FOR
SOLID WASTE COLLECTION**

By

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TABLE OF CONTENTS

Chapter	Page
I. INTRODUCTION	1
Objectives	2
II. LITERATURE REVIEW	3
Refuse Collection	3
Cost of Solid Waste Collection	4
Systems of Collection	8
Mechanized Curbside Pickup	8
Bionomics System	8
Vacuum Systems for Refuse Collection	9
Set-out and Set-back System	10
Refuse Collection Equipment	10
Containers	10
Cylindrical Metal Containers	11
Plastic Bags	11
Trucks	11
Routing	12
Daily Route Method	12
Large Route Method	13
Single Load Method	13
Definite Working Day	14
Chinese-Postman Problem	14
The Traveling Multi-Salesman Problem	14
III. METHODS AND RESULTS	17
Step 1. Determine Characteristics of the Area	20
Step 2. Locate the Sanitary Landfill Site	21
Step 3. Determine the Required Number of Collection Trucks	22
Establish Design Values (a)	22
Determine Solid Waste Generated per Day per City (b)	23
Place Each City Into One of Three Groups (c)	24
Determine the Total cu yds of Residential and Commercial Refuse per Day of Collection (d).	26
Determine the Number of Collection Stops Made by Different-sized Refuse Trucks (e)	28
Determine the Number of Refuse Collection Trucks and the Macro Routing for Each Truck per Day of Refuse Collection (f)	31

Chapter	Page
Micro Routing (g)	34
Step 4. Determine Total Annual Collection Costs	38
Example	40
Step 1. Determine Characteristics of the Area	40
Step 2. Locate the Sanitary Landfill Site	44
Step 3. Determine the Required Number of Collection Trucks	49
Establishing Design Values	49
Determine Solid Waste Generated/day/city	50
Place Each City Into One of Three Groups	51
Determine the Total cu yd of Residential and Commercial Refuse per Day of Collection	52
Determine the Number of Collection Stops Made by Different-sized Refuse Trucks	54
Determine the Number of Refuse Collection Trucks and the Macro Routing for Each Truck per Day of Refuse Collection	57
Step 4. Determine Total Annual Costs	63
IV. DISCUSSION	65
V. CONCLUSIONS	68
VI. SUGGESTIONS FOR FUTURE WORK	69
A SELECTED BIBLIOGRAPHY	70

LIST OF TABLES

Table	Page
I. Composition of a Sample of Municipal Solid Waste	7
II. Total Number of Days of Refuse Accumulation for Each Group of Cities	18
III. Amount of Commercial and Residential Refuse of Each City	24
IV. Cubic Yards of Residential Refuse per Day of Collection of Each Group	26
V. Commercial Waste Generation for Each City per Day of Collection	27
VI. Makeup of Labor Force	42
VII. Housing Conditions	43
VIII. Quality of Present Waste Collection Facilities	43
IX. An Approximate Percentage of Households in Seminole .	44
X. Shortest Distance Between Cities in Seminole County .	45
XI. Cu Yd Commercial and Residential Refuse Generation in Every City per Day	51
XII. Residential Refuse Generated in Each City per Collection Day	53
XIII. Commercial Refuse Generation for Each City per Day of Collection	54
XIV. Total Time of Pickups (Collections) and the Number of Collection Stops per Day	62

LIST OF FIGURES

Figure	Page
1. Kinds and Amounts of Solid Waste Generated Annually in the U. S. A.	5
2. A Breakdown of Costs to Communities for Refuse Handling by Public Health Service Tennessee (4)	6
3. Specific Routing Pattern for One-way Street, One-side-of-the-street Collection	35
4. Combinations of Four-block Pattern, One-side-of-the-street Collection	36
5. Specific Routing Patterns	37
6. Outline Map of Oklahoma	41
7. Location of Landfill in Seminole County, Seminole City	48

CHAPTER I

INTRODUCTION

Solid waste is the residue of man's economic and social activities that is handled in bulk rather than disposed of directly into the land, water, or air. Thus, agricultural refuse, manufacturing scrap, the worn-out auto, the empty beer can, and yesterday's newspaper are all examples of solid waste. Normally, we view individuals in our society as consumers, but each might better be called a transformer, taking in large quantities of goods, foods, or whatever, and transforming the greater share of them, sooner or later, into solid waste. If this world is to sustain a reasonably esthetical environment, minimize health hazards, and conserve natural resources, this solid waste must be collected, processed, reclaimed if possible, and ultimately returned to the environment in an intelligent manner. In fact, solid waste is potentially a resource worth billions of dollars; however, much of this potential flounders on the problems presented by one simple basic fact: most municipal solid waste is not treated where it is generated.

In an endless number of locations throughout the world, people are engaged in activities that generate solid waste on farms, at mining sites, in households, factories, commercial establishments, and government facilities. Each type of activity produces waste with a different composition in a different period of time. Collecting this waste, i.e., picking it up and transporting it to treatment and/or disposal sites,

causes by far the greatest drain on the funds available for solid waste management. According to Black (20) in his research concerning the solid waste problem in metropolitan areas, collection consumes up to 85 percent of the total cost. Even then, much is lacking in the collection operation. A small, yet all-too-large fraction of the municipal solid waste shortcircuits the system, often ending up in streets or alleys, back yards, or rivers. Consequently, if better methods of disposal and/or recycling are to be achieved and used, if urban eyesores are to be cleaned up, and if effective solid waste management is to be realized within the limited budgets available, the collection systems must be improved.

Objectives

The purpose of this research was to develop an efficient method and a feasible solution of macro routing problems for solid waste collection. Macro routing problems are an inherent part of any collection system.

CHAPTER II

LITERATURE REVIEW

Refuse Collection

This is a complex system to analyze, primarily because it involves both manpower, equipment, and levels of service plus the possibility for numerous variations in secondary factors which are difficult to quantify but have a direct bearing on the overall efficiency of the system. Some of these factors are collection methodology, quantity, nature, and method of storage of the refuse, location of pickup points, equipment type and characteristics of operation, road factors, service density, route topography, climatic factors, and a broad category termed, for lack of a better description, human factors. Human factors including morale, motivation, fatigue, and other psychological and physiological factors which influence the time required to complete a given work task.

Refuse immediately brings to mind the garbage collector and mountains of trash in open dumps. With ninety percent of the people living in or near metropolitan areas, it is not surprising that most of us view the solid waste problem in terms of trash, its generation by each household, its collection, and its ultimate disposal--usually in an unsightly, smelly, smoldering, unsanitary dump. However, although trash is of primary concern, it comprises only one small part of the

total solid waste stream; municipal solid waste, collected and uncollected, represents less than one-tenth of the total solid waste generated in the United States annually, as shown by Figure 1. David Gordon Wilson (3) in Figure 1 points out that municipal waste is the smallest by weight, 360 million tons per year. However, it constitutes the most immediate and obvious problem area in that the greatest portion of municipal waste--190 million tons per year--is that collected in regular pickups, namely, routing trash from residences, businesses, and institutions of various kinds. Thus, gathering this material is no easy task, since waste is produced wherever people live or work; collection must extend over a broad geographical area.

Today, collection requires the highest percent of the total municipal funds available for solid waste handling, as shown in Figure 2.

In addition, the high cost of collection plus the complex composition of the waste, as shown in Table I by Robb Tyler (5), has resulted in disposal of municipal solid waste rather than recovery. Only small quantities are recovered, even though it represents potentially several billion dollars worth of material values.

Cost of Solid Waste Collection

According to Marks and Liebman (1), some 4.5 to 5 billion dollars a year is spent collecting municipal solid waste. Also, it has been reported that refuse collection accounts for the third largest municipal expenditure, ranking next to education and streets/highways (6). A part of this expense is the cost of cleaning up areas where litter is prevalent. Flintoff and Millard (7) came up with an estimation that the current bill for collecting municipal park and highway litter

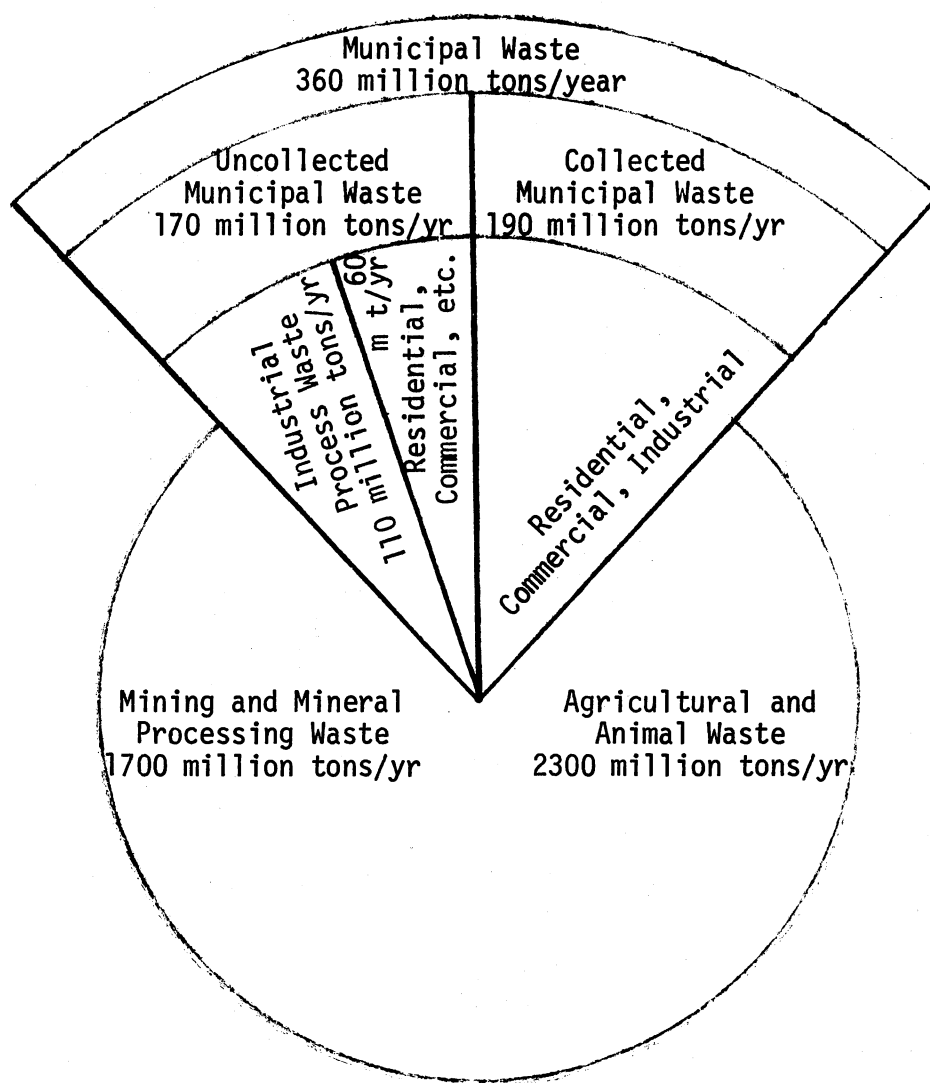


Figure 1. Kinds and Amounts of Solid Waste Generated Annually in the U. S. A.

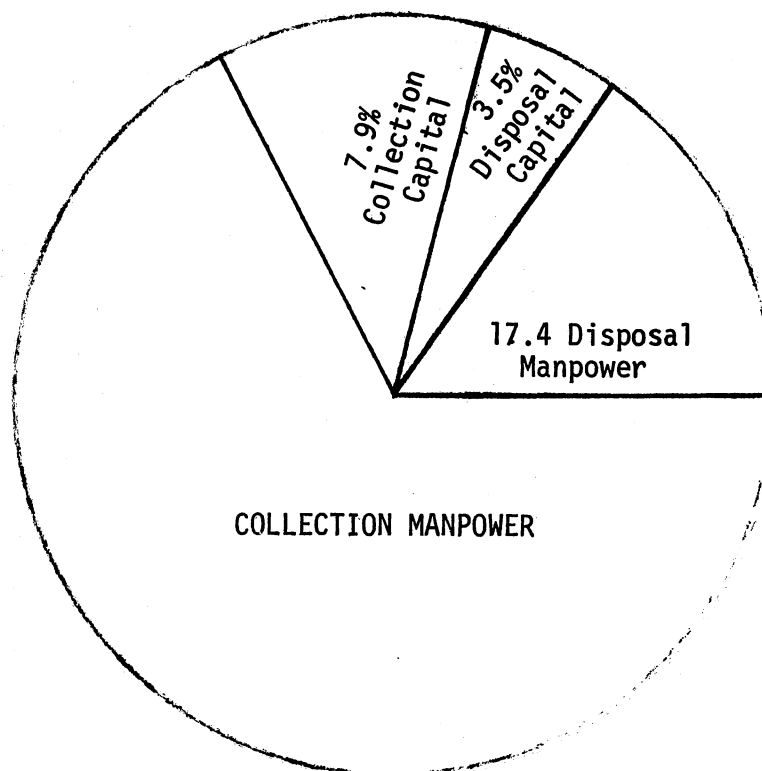


Figure 2. A Breakdown of Costs to Communities for Refuse Handling by Public Health Service, Tennessee (4)

is about five million dollars per year. Thus, without some basic improvements in the environmental husbandry practiced by all citizens, the task of bringing our environment into a reasonably esthetical condition will take monumental amounts of manpower and funds.

TABLE II
COMPOSITION OF A SAMPLE OF MUNICIPAL SOLID WASTE

Type of Material	% by Weight	Partial Chemical Analysis	% by Weight
Cardboard	7	moisture	28.0
Newspaper	14	carbon	25.0
Miscellaneous paper	25	hydrogen	3.3
Leather, molded plastics	2	nitrogen	0.5
Rubber garbage	12	sulfur	0.1
Grass and dirt	10	glass, ceramic, stones	9.3
Textiles	3	metals	7.2
Wood	7	ash	5.5
Glass, ceramic, stones	10		
Metallics	<u>8</u>		
TOTAL	100		100.0

J. Summer (8) recognized that the major reason for the poor return of current cost investments is the inefficient way manpower is used in present collection systems. At the very least, ninety percent of the

nation's collected refuse is picked up by hand and carted off to trash cans or incinerator chutes, where it is handled subsequently by yet other hands. However, a very few new collection techniques have been implemented either in the United States or abroad. Many possibilities, such as the following, could improve collection.

Systems of Collection

Mechanized Curbside Pickup

Mechanized curbside pickup, with various sized crews such as the "one man refuse truck" is reported by Robert L. Jewell (9). This system consists of one man serving as the driver and as the loader. Jewell reported that between 8:00 A. M. and 2:30 P. M., an inexperienced driver collected 478 stops, plus making one trip to the incinerator and taking one hour for lunch.

Bionomics System

The one-man nonstop collection system, or the bionomics system, has been tested by the Bionomics International L. T. D. (10). "Bionomics" means efficient and economic use of man-machine systems for improvement of man's environment; in other words, the economics of ecology. This system works in the following manner: One man operates a nonstop truck incorporating a unique, patented, mechanical method of picking up, dumping, and returning containers to their original position. The E.P.A.'s final report states that the system is the most modern, economical, fast, safe, popular, sanitary residential refuse collection system in the world today. Also, the report describes the system fully and

comments that it is the development of a non-stop, one-man refuse collection operation that is five times as productive as the old conventional rear-loader collection system it replaces.

Vacuum Systems for Refuse Collection

According to Robinson (11), the present orders for vacuum systems to collect solid waste represent 330 projects around the world, with most to be operating within two years. In addition, Hallstrom (23), managing director of Centralsug in Stockholm, stated that

This firm, owned by Color-Celius, Sweden's largest maker of piping, has done much development in pneumatic collection systems and installed its first in northern Sweden and in Florida's Walt Disney World (page 8).

Moreover, other systems are slated for a Westminster housing project outside London; in Grenoble, France, Caracas, Venezuela, and four locations in West Germany including the 1972 Olympic Village at Munich. Also, Zandi (1) has proposed an extensive pipeline system for moving solid wastes under pressure as an alternative to refuse collection in order to eliminate truck routing in crowded cities.

The advantages of the pneumatic systems claimed by Robinson (11) are: no labor, vehicular access of refuse storage requirements, refuse is moved to the central disposal point continuously throughout the day including Saturdays and Sundays; there is no spillage, odor, or noise. Although it is not claimed that initially it is comparable economically with any other of the more conventional systems, the promoters consider that as costs of other methods continue to rise with monetary inflation and the volume of refuse continues to increase, the system will prove to be competitive and ultimately to be more economical.

Set-out and Set-back System

This system has been described by the American Public Works Association (12) as a system consisting of a member of the crew setting out refuse from the back yard, and either the householder or a member of the crew returning the empty refuse container to the back yard location. Stone and Company, Inc., Engineers (2), have determined that a one-man crew is the most efficient in collecting refuse under normal curbside collection procedures. It follows that the overall efficiency of the set-out and set-back system of refuse collection would be improved when combined with curbside collection if the one-man crew were used. Also, the number of men needed to set out refuse from the back yard location to the curb would depend on the quantity of refuse per service stop and the scheduling necessary to preclude the collection vehicle's overtaking them. Normally, the set-out operations would begin prior to the curbside collection operation in order to save time of the truck.

Refuse Collection Equipment

In every collection system, the types of equipment affect directly or indirectly the feasibility of the routing system and some other ethical and environmental conditions, as shown in the following sections.

Containers

According to Seabloom (21), containers come in capacities from one to thirty cubic yards and in two general categories. Roll-on, roll-off containers, which are normally in the upper end of the size range, are removed bodily by a specially equipped vehicle. The other general type

of container is one which is hoisted in some way and tipped into the rear hopper of a conventional packer collection truck or into the overhead doors of a front-end load-in truck. However, these two categories of containers have a direct effect upon the routing time--mostly if the containers are metal or plastic, as shown in the following discussions.

Cylindrical Metal Containers. These are used to store refuse by most home owners and many businesses but, according to the E.P.A., they have a number of disadvantages, such as the following:

- 1) metal cans become unsightly
- 2) they bend easily
- 2) they rust easily and fall apart
- 4) the metal cans are heavy, noisy, and difficult to keep clean; consequently, they have a tremendous effect upon the routing time and especially upon the workability, and
- 5) covers on metal cans are easily lost and the cans are easily blown by the wind.

Plastic Bags. According to the American Public Works Association (12), plastic bags are applicable and have more advantages than do metal containers. They make collection easier and save a lot of routing time. Moreover, they are easier to carry and are better looking than the metal cans, easier to clean and last longer. Better movability is achieved by using plastic bags than by using metal cans.

Trucks

It is pertinent to point out that the success of any collection system will depend in large part on the proper selection of equipment.

The major reason for the overall importance of collection equipment is the need for mechanization of the collection operation. In addition, the conditions and policies existing in any community will dictate which particular type and make of collection body is best suited for its service. The American Public Works Association (12) suggests that each community must make its own evaluation and selection. In evaluating the different types available, diligent study should be given to the characteristics of each type, particularly those directly affecting the performance of the collection employees and routing of the truck, such as the following characteristics:

- 1) efficient height of the loading edge from the ground
- 2) effective width of the loading hopper
- 3) overall loading space, including vertical clearance
- 4) time of loading, packing cycle, and the degree of compaction
- 5) any inherent safety hazards, location and ease of actuating controls, appearance of the truck, and cost, and
- 6) ruggedness and ease of maintenance and the desirable turning radii.

Routing

Several methods for solid waste routing have been developed. The method should be chosen considering labor work-day restraints, such as eight hours per day. According to Seabloom (21), some of these methods are:

Daily Route Method

In this method, the crew is assigned a route for a certain day, and

the work day is completed when the route is completed. It has the advantage of being an incentive for the crew members to make routing become more efficient. In addition, the householder knows the day of collection, and the containers will be ready to be picked up. Also, the daily route method has a few disadvantages, such as when a holiday is disrupted because it occurs on the same day of the scheduled route. In addition, it might create labor or union conflicts.

Large Route Method

In this method, layout of a one-week route is assigned, and the crew can leave when the route is complete. This type of routing has been used efficiently by the public worker in the '60s and the mid-'70s in most of the United States. This type of routing promotes incentive and provides flexibility in the case of holidays; also, it has the advantage of using the equipment for other purposes after the route is complete. However, the large route method has a disadvantage because it creates an irregular collection time. This has a significant effect upon the efficiency of the route, and it is usually difficult to determine a weekly route.

Single Load Method

This is the method of using a variation in the daily route of collection, where the route is laid out to provide full loads when the refuse is collected and the truck will not terminate its route until the truck is completely full. This method has the advantage of providing a full day's work, and the time is spent efficiently. Also, it creates a regular day of collection. However, it has the disadvantage

of following a route that is difficult to remember and a variation in the amount of refuse creates problems.

Definite Working Day

A definite working day is similar to the large route method, but here the crew has to start over as soon as it finishes the route. This type of routing has the advantage of creating no overtime work, which most private refuse collectors dislike. Also, it has the disadvantage of creating an irregular frequency of collection, and it adds little incentive.

Chinese-Postman Problem

As defined by Marks and Liebman (1), this is the process of finding the minimum distance continuous tour through a network which travels all arcs at least once. Thus, it is an arc-covering problem. In fact, many studies have been done on this problem, but none shows that it is applicable in all cases, especially in conflict of constraints such as time of the route and full load of the truck.

The Traveling Multi-Salesman Problem

The T. M. S. problem has been the target of a substantial number of computational algorithms over the last two decades. Reported computational experience with these algorithms varies widely. Authors, however, have generally failed to explain this variation adequately or to offer predictive theories for their approaches. The problem is perhaps the most simply stated of all unsolved combinatorial problems. It is this deceptive simplicity that has attracted an unending stream of

challengers, encouraged by the large number of potential applications for a practical technique of finding exact solutions to large problems. The problem derives its name from the route choice; the salesman must visit each of N cities in sequence and return home, minimizing his total mileage. In fact, it is a node-covering problem.

In the content of solid waste collection is the problem of the traveling multi-salesman representing the routing of solid waste collection vehicles from landfill or incinerator through their individual collection tasks. The T. M. S. are solid waste collection vehicles, the terminals are landfills, and the cities are small collection areas, each of which generates an amount of solid waste per time period. Marks and Liebman (1) did a mathematical programming formulation of the traveling multi-salesman problem trying to minimize the distance traveled by the collection vehicles, as shown:

$$\text{Minimize } \sum_{i=1}^N \sum_{j=1}^N L_{ij} X_{ij} + \sum_{t=1}^S \sum_{c=1}^N \left(d_{ct} X_{ct} + d_{tc} X_{tc} \right) \quad (1)$$

Subject to

$$\sum_{c=1}^N X_{ct} = \sum_{c=1}^N X_{tc} \quad \text{where } t=1,2,\dots,S \quad (2)$$

$$\sum_{i=1}^N X_{ij} = \sum_{i=1}^N X_{ji} \quad \text{where } j=1,2,\dots,N \quad (3)$$

$$\sum_{i=1}^N X_{ij} = 1 \quad \text{where } j=1,2,\dots,N \quad (4)$$

$$\sum_{c=1}^N X_{tc} = M \quad \text{where } C=1,2,\dots,S \quad (5)$$

$$X_{ct}, X_{tc}, X_{ij} \text{ are non-negative integers} \quad (6)$$

where

J_{ij} = number of trucks traveling from city i to city j

X_{ct} = number of trucks traveling from city c to landfill, etc., t

X_{tc} = number of trucks traveling from t to c

L_{ij} = distance from city i to city j ($d_{ii} = \infty$)

d_{ct} = distance from city c to terminal t

d_{tc} = distance from landfill, etc., t to city c

M = number of trucks dispatched from each landfill

N = number of cities

S = number of landfills

where equation (1) is the objective function, which is the minimization of the distance traveled by the trucks.

Equations (2) and (3) express continuity of flow requirements for each landfill and for each city, respectively. They require that the number of trucks entering a landfill or city must equal the number leaving it.

In equation (4), the requirement that exactly one truck must visit each city is expressed, while in equation (5), all trucks must visit the landfill.

Marks and Liebman (1) comment that this mathematical programming model minimizes only the distance but it does not minimize the number of trucks or the number of crews. They add that algorithmic functions are not applicable in most cases and for this reason some heuristic adjustment is always necessary.

CHAPTER III

METHODS AND RESULTS

In exploring the different systems of refuse collection, it was recognized that the different combinations of days of refuse collection and the grouping of the cities would have a great effect upon the required truck capacity. Thus, a trial and error procedure was used to determine the best routing procedure.

In the first trial, the cities were divided into two groups with the following days of residential refuse collection determined for each group:

Group one collected on Monday and Thursday

Group two collected on Tuesday and Friday.

Also, the commercial refuse of the two groups was to be collected five days per week, as shown in Table II.

Table II indicates that the required number of trucks for residential refuse collection will be determined from the four days of refuse accumulation. Similarly for the commercial refuse, the required number of trucks will be determined by the cubic yards of refuse accumulated in three days. It was found that all of the refuse trucks are free on Wednesday, which affects the economic feasibility. On Thursday and Friday there are always more than two trucks free. The required number of commercial trucks for Monday's collection would be three times the number required for the rest of the week, which indicates

that many of the trucks would be idle. In addition, an adjustment was tried between the residential refuse trucks and the commercial refuse trucks, but no feasible adjustment was found.

TABLE II
TOTAL NUMBER OF DAYS OF REFUSE ACCUMULATION FOR
EACH GROUP OF CITIES

	Mon.	Tue.	Wed.	Thur.	Fri.
Number of days of residential refuse accumulated for group one	4			3	
Number of days of residential refuse accumulated for group two		4			3
Number of days of commercial refuse accumulation	3	1	1	1	1

In the second trial, the same truck would collect both residential and commercial refuse. The total required truck capacity was found to be 176 cu yd/day; however, on Monday the required number of trucks was three times that required for any other day. This was because of the quantity of refuse accumulated over Friday, Saturday, and Sunday. Thus, if the 176 cu yd/day of refuse was used as a required truck capacity, many of the trucks would be idle the rest of the week, creating an inefficient situation.

The third trial was to use the same combination of days of refuse

collection as the first trial. However, in addition, some cities would be scheduled to be collected on Wednesday. The commercial refuse collection schedule was also extended to six days per week. In order to reach a suitable adjustment of a combination of grouping of cities and commercial refuse and residential refuse collection days, the following factors were considered:

The cities should be separated into three groups based upon the total collection stops, with collections made on the following days:

Group I - collection on Monday and Thursday

II - collection on Tuesday and Friday

III - collection on Wednesday.

This combination of days of refuse collection was adjusted to satisfy the residential and commercial refuse according to E.P.A. standards of six days per week of commercial refuse collection, and one or two days per week of residential refuse collection. This would reduce the number of trucks and manpower requirements based upon a 5-day, 40-hour work week schedule.

In order to confine residential pickup to two days per week, except for Group III which is only one day per week, the following program was tried. On Wednesday, various crews would be retired and assigned to the commercial pickup on Saturday. The Saturday pickup would be during the evening hours so that the solid waste generated during Saturday's business hours would not be stored on site during Sunday. Also, this would help to maximize efficiency by maximizing the use of the trucks.

To categorize the groups, consideration must be given to density of population, commercial establishments in the area, and economic

status of the population. The method developed consists of four major steps:

- 1) determine characteristics of the area
- 2) locate the sanitary landfill site
- 3) determine the required number of collection trucks. This is done by using the following steps:
 - a) establish design values
 - b) determine solid waste generated per day per city
 - c) place each city into one of the three groups for collection
 - d) determine the total cu yd of residential and commercial refuse per day of collection
 - e) determine the number of collection stops made by different-sized refuse trucks
 - f) determine the number of refuse collection trucks and the macro routing of each truck per day of refuse collection
 - g) micro routing
- 4) determine total annual collection costs.

Each step is explained in detail below.

Step 1. Determine Characteristics of the Area

A brief social picture of the county or the city should be studied and presented. This should include the number of housing units, population, standard of living, number of residential and commercial collections, present collection facilities, weather, etc. The importance of this step is to reflect to the designer what quality of a system should be used, and what condition and quantity of refuse there is to be collected. It also helps the designer to pick the design period for

the system to be used.

Step 2. Locate the Sanitary Landfill Site

The centralization of the landfill is based upon locating the first centroid between the first two cities, then the second centroid with respect to the first centroid and the third city. The centroid is based upon the number of collections of each city and the distance between them. Thus, this process is continuous until all cities at the design area are covered. The last centroid located is the location of the landfill.

The following two equations are used to locate the landfill:

$$d_1 + d_2 = D \quad (1)$$

$$C_1 d_1 = C_2 d_2 \quad (2)$$

where

d_1 = distance of city one in miles from the centroid

d_2 = distance of city two in miles from the same centroid

D = total distance between city one and city two in miles

(usually it is best to consult the state highway department maps to find the shortest possible distance between cities)

C_1 = number of collections at city one

C_2 = number of collections at city two.

Thus, equations (1) and (2) with two unknowns, d_1 and d_2 can be calculated.

Step 3. Determine the Required Number of Collection Trucks

This part of the procedure determines the number of collection trucks required. There are several steps that must be taken to make this determination. Each of the steps is explained below.

Establish Design Values (a)

Design values should be collected from the design area by sampling, surveying, and the use of ingenuity by the designer. The values to be established are:

1) pounds of refuse per business per week. This number should be determined four times per year--once in each quarter of the year. This will provide an average weight of refuse generated throughout the year.

2) total number of pounds of refuse per capita per day (commercial + industrial + institutional + residential). This number should be determined twenty-four times per year--twice each month, preferably on the first of the month and at the end of the month, thereby averaging the weight of the refuse in proportion to the cost of collection.

3) solid waste (lbs/cu yd) compacted in the trucks. This number can be obtained from the truck manufacturer.

4) highway speed limit mi/hr. This can be obtained from the highway department.

5) number of residential and commercial refuse collections. This can be obtained by driving and surveying the area of design.

6) population of each city. This can be obtained from an official census.

7) time needed per residential and commercial refuse pickup. This can be determined from detailed analysis of solid waste collection systems presently used in the field.

8) update prices of refuse collection trucks. Usually it is best to consult refuse truck markets and companies.

9) cost of maintenance, oil, gas, etc., per hour. This can be determined from previous data systems and from company listings.

10. miscellaneous costs, such as equipment repair and parts replacement costs. These can be obtained from manufacturers' listings.

11) wages of solid waste employees. Payment will be according to current wage scale of the design area.

12) percent cost of supervision, fringe benefits (i.e., social security and medical insurance), and contingencies such as unforeseeable future costs can be estimated between the range of 10 to 20 percent of the present personal costs and equipment costs.

13) total time per day for micro traveling for residential and commercial refuse collection excluding time per collection stops. This can be estimated between the range of 2-3 hours and 3-3.5 hours for residential refuse and commercial refuse collection micro traveling, respectively.

Determine Solid Waste Generated per Day
per City (b)

The solid waste generated per day per city can best be determined by using Table III.

TABLE III
AMOUNT OF COMMERCIAL AND RESIDENTIAL REFUSE OF EACH CITY
(cu yd/day)

1 City	2 Number of Residential Collections	3 Number of Commercial Collections	4 Population	5 Commercial Refuse cu yd/day	6 Residential Refuse cu yd/day

The values for column 5 are calculated by the following formula:

$$\text{commercial refuse} = \frac{[\text{lbs/business week}][\text{number of commercial collections}]}{[\text{7 days/week}][\text{lbs/cu yd compacted}]}$$

The values of column 6 are calculated by the following formula:

$$\text{residential refuse} = \frac{[\text{total lbs/capita/day of refuse}][\text{population}]}{[\text{lbs/cu yd compacter}]}$$

$$- [\text{values of column 5}]$$

Place Each City Into One of Three Groups (c)

The purpose of this step is to divide the total number of residential refuse collection stops into three groups. These groups will be arranged by cities. The number of residential refuse collection stops for the cities of Group III should sum to less than the collection stops for cities of Groups I and II. Instead of all crews working on Wednesday, some can take Wednesday off and thus be used for Saturday's

commercial collection. It is suggested that the number of residential refuse collection stops of Group III be equal to a certain fraction (usually between 0.05 and 0.06) of the total number of residential refuse collection stops of the whole area of design. This value will allow three or four crews from Group III to be idled during the week for activation on Saturday's commercial refuse collection. The value of the constant should be lowered as more trucks are required for Saturday's commercial refuse collection.

This grouping procedure can be mathematically expressed as follows:

$$X = KS$$

Hence $(S - X) \div 2 = y = z$

where

X = number of residential refuse collection stops for cities of Group III

K = fraction ranges between 0.04 to 0.06 (varying with the number of crews to be idled on Wednesday and the need for crews on the Saturday commercial refuse collection)

S = total number of residential refuse collection stops in the area of design

2 = in order to make the number of residential refuse collection stops for Group I equal to those of Group II

$y = z$ - number of residential refuse collection stops of Group I or Group II.

Minimizing traveling time and the degree of population and industrialization should be the criterion for grouping cities into the three groups. Group III should not be heavily industrialized or of high

population density, since the refuse will be allowed to accumulate for seven days. Selection of cities for Groups I and II should be made so that the proximity of the cities allows less traveling time. Such cities will not be fragmented into more than one group, if possible.

Determine the Total cu yds of Residential and Commercial Refuse per Day of Collection (d)

The residential cubic yards of residential refuse accumulated per day of collection of each group is tabulated, as shown in Table IV. Assume cities A and B are in Group I, cities C, D, and E are in Group II, and city F is in Group III. The following tabulation results:

TABLE IV

CUBIC YARDS OF RESIDENTIAL REFUSE PER DAY OF COLLECTION OF EACH GROUP

cu yd/day of Residential Refuse of Each City		Number of Days of Residential Refuse Accumulated				
City		4 Mon.	4 Tues.	7 Wed.	3 Thur.	3 Fri.
A	U	Group I			Group I	
B	V	Group I			Group I	
C	W		Group II			Group II
D	X		Group II			Group II
E	Y		Group II			Group II
F	Z			Group III		
Total cu yd/day Residential Collection		α		Σ		λ
Total Truck Capacity Needed cu/yd*		$\frac{\alpha}{2}$	$\frac{B}{2}$	$\frac{\Sigma}{2}$	$\frac{W}{2}$	$\frac{\lambda}{2}$

*based upon each truck making two trips to landfill

$\frac{\alpha}{2}$ and $\frac{B}{2}$ are in close value because of the grouping in step c. $\frac{W}{2}$ and $\frac{\lambda}{2}$ will be less than $\frac{\alpha}{2}$ and $\frac{B}{2}$ because less days of solid waste accumulation but the same number of refuse collection stops. $\frac{\Sigma}{2}$ will be much less than either of the two groups, and much less in the number of collection stops.

Similarly, the cubic yards of commercial refuse per day of each city is tabulated in Table V.

TABLE V
COMMERCIAL WASTE GENERATION FOR EACH CITY PER DAY OF COLLECTION

City	cu yd/day	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.*
A	O	O	O	O	O	O	2O
B	P	P	P	P	P	P	2P
C	Q	Q	Q	Q	Q	Q	2Q
D	R	R	R	R	R	R	2R
E	S	S	S	S	S	S	2S
F	T	T	T	T	T	T	2T
Total cu yd/day Commercial Ref. Collection		N	M	L	K	J	I
Total Truck Capacity Needed cu yd		$\frac{N}{2}$	$\frac{M}{2}$	$\frac{L}{2}$	$\frac{K}{2}$	$\frac{J}{2}$	$\frac{I}{2}$

*The commercial cu yd of refuse is multiplied by 2, because it is an evening collection.

The total truck capacity for residential refuse should not be less than $\frac{\alpha}{2}$ or $\frac{B}{2}$ (Table IV). Similarly, the total truck capacity for every day commercial refuse collection should not be less than $\frac{N}{2}$ (Table V). $\frac{I}{2}$ is always double $\frac{N}{2}$ because the commercial refuse collection will be in the evening on Saturday, and the commercial refuse will have been accumulated from Friday and Saturday.

Determine the Number of Collection Stops

Made by Different-sized Refuse Trucks (e)

The number of stops made by the different available sized trucks for each day of residential and commercial refuse collection should be determined. The values calculated in this step show how many collection stops are necessary for each different sized truck to utilize efficiently its capacity to pick up the refuse that is accumulated on each work day. This procedure can be expressed mathematically by the following relationships:

Monday. α (Table IV) \div y (step c) = X cu yd residential refuse/collection stop. Hence, to see how many collection stops for different sized trucks available, we see:

Truck size

30 cu yd \div X cu yd/collection stop = A collection stops

20 cu yd \div X " = B "

18 cu yd \div X " = C "

16 cu yd \div X " = D "

14 cu yd \div X " = E "

12 cu yd \div X " = F " , etc.

Tuesday. B (Table IV) $\div Z$ (step c) = X_1 cu yd residential refuse/
collection stop.

Truck size

30 cu yd $\div X_1$ =	cu yd/collection stop =	P_1	collection stops
20 cu yd $\div X_1$ =	"	= B_1	"
18 cu yd $\div X_1$ =	"	= C_1	"
16 cu yd $\div X_1$ =	"	= D_1	"
14 cu yd $\div X_1$ =	"	= E_1	"
12 cu yd $\div X_1$ =	"	= F_1	" , etc.

Wednesday. Σ (Table IV) \div (step c) = X_2 cu yd/collection stop.

Truck size

30 cu yd $\div X_2$ =	cu yd/collection stop =	A_2	collection stops
20 cu yd $\div X_2$ =	"	= B_2	"
18 cu yd $\div X_2$ =	"	= C_2	"
16 cu yd $\div X_2$ =	"	= D_2	"
14 cu yd $\div X_2$ =	"	= E_2	"
12 cu yd $\div X_2$ =	"	= F_2	" , etc.

Thursday. W (Table IV) $\div y$ (step c) = X_3 cu yd/collection stop.

Truck size

30 cu yd $\div X_3$ =	cu yd collection stop =	A_3	collection stops
20 cu yd $\div X_3$ =	"	= B_3	"
18 cu yd $\div X_3$ =	"	= C_3	"
16 cu yd $\div X_3$ =	"	= D_3	"
14 cu yd $\div X_3$ =	"	= E_3	"
12 cu yd $\div X_3$ =	"	= F_3	" , etc.

Friday. λ (Table IV) \div Z (step c) = X_4 cu yd/collection stop.

Truck size

30 cu yd \div X_4 = cu yd/collection stop = A_4 collection stops

20 cu yd \div X_4 = " = B_4 "

18 cu yd \div X_4 = " = C_4 "

16 cu yd \div X_4 = " = D_4 "

14 cu yd \div X_4 = " = E_4 "

12 cu yd \div X_4 = " = F_4 " , etc.

Every Day Commercial Refuse Collection. N (Table V) \div total collections (Table III column 3) = X_5 cu yd/collection stop.

Truck size

30 cu yd \div X_5 = cu yd/collection stop = A_5 collection stops

20 cu yd \div X_5 = " = B_5 "

18 cu yd \div X_5 = " = C_5 "

16 cu yd \div X_5 = " = D_5 "

14 cu yd \div X_5 = " = E_5 "

12 cu yd \div X_5 = " = F_5 " , etc.

Commercial Refuse Collection on Saturday. I (Table V) \div total collections (Table III column 3) = X_6 cu yd/collection stop.

Truck size

30 cu yd \div X_6 = cu yd/collection stop = A_6 collection stops

20 cu yd \div X_6 = " = B_6 "

18 cu yd \div X_6 = " = C_6 "

16 cu yd \div X_6 = " = D_6 "

$14 \text{ cu yd} \div X_6 = \text{cu yd/collection stop} = E_6 \text{ collection stops}$

$12 \text{ cu yd} \div X_6 = \text{ " } = F_6 \text{ " }, \text{ etc.}$

Usually, the same-sized truck makes more collection stops on Thursday and Friday than the collection stops on Monday and Tuesday, because of less days of solid waste accumulation on Thursday and Friday (see Table IV).

Determine the Number of Refuse Collection

Trucks and the Macro Routing for Each Truck

per Day of Refuse Collection (f)

Daily macro routing for each truck is to be planned for two trips to the landfill per day based upon normal truck collection stops from step e. The trucks should be assigned routes in areas involving the minimum distance between the cities and the landfill. A truck will first be assigned to one of the cities in the area. Then the truck will be assigned a route which will make use of its full capacity. Such a route might include stops in more than one city. The route of the trucks and the combination of truck sizes are determined by the following procedure:

The truck with the largest number of collection stops from step e is initially dispatched on Monday to the Group I city having the greatest quantity of refuse and consequently the greatest number of collection stops. The truck is filled to capacity and then returned to the landfill. On the next trip, the truck collects as much of the remaining collection stops of refuse as is possible and again returns to the landfill. If all of the refuse collection stops in one city are

made before the end of the working day, then the truck will go to a second or third city and collect refuse up to its collection stops capacity before returning to the landfill. Conversely, if two trips from one truck are not sufficient to make all of the refuse stops in one city, then a second truck is dispatched to the city to service the balance of residential refuse collection stops. For maximum efficiency and utility, it is necessary that all of the trucks be filled to capacity on both landfill trips, particularly on Monday and Tuesday, as will be further explained in this step.

Since the total macro routing time of the assigned truck route is known, total break time is also known (step e) and the total time necessary for micro traveling time is known (step a). Hence, the time left for collection stops can be determined by the following procedure:

$$L \div V = K$$

Hence $(K) + (B) + (X) = (8 - S)$. Therefore $X = (8 - S) - K + B$. Since (X) can be determined, then the number of collection stops can be calculated as follows:

$$N \times \frac{E}{60} = X$$

$$\text{or } N = (60X) \div E$$

where

L = total macro traveling miles (step 2)

K = total macro traveling time in hours

V = highway speed limit

B = total time in hours for breaks per day (step a)

X = total time available for collection stops

8 - S = time left per work day excluding micro traveling time (S)
(step a)

E = time in minutes needed per collection stop (step a)

N = total number of collection stops that truck can make in
time (X).

After solving for (N), go back to step e and find the smallest size truck that can collect (N) number of stops. Similarly, this process is continued until all of the collection refuse stops for Monday are made. The total amount of truck capacity on Monday determined should not be less than α (Table IV) and the total number of refuse collection stops of the fleet determined should not be less than y (step c).

The same procedure for determining truck combinations should be followed for Tuesday by applying the same procedure as on Monday. The number and the sizes of the refuse trucks that have been determined to satisfy Monday's and Tuesday's refuse collections will therefore satisfy Wednesday, Thursday, Friday, and Saturday's commercial refuse collections. This is because of the grouping in step c. Also, because they will have the same number of collection stops but less cu yd of refuse generated (Table IV). On Wednesday, almost half of the trucks will be idled because of the grouping in step c, but they will be working on Saturday evening for commercial refuse collection.

In case there is not enough time for a certain number of collection stops for a given truck, the macro route of the truck must be shortened so that the necessary number of collection stops for the truck to be filled may be made.

Micro Routing (g)

For micro routing in each city, each truck needs around two to three hours per day for residential refuse collection excluding the collection stops time. And three to three and a half hours per day for commercial refuse collection. The following heuristic rules should be applied in order to minimize the routing time:

- 1) Collections on heavily traveled streets should not be made during rush hours.
- 2) Routes should not be fragmented or overlapping. Each route should be compact, consisting of street segments clustered in the same geographical area.
- 3) For collection from both sides of the street at the same time, it is generally best to route with long, straight paths across the grid before looping clockwise.
- 4) In the case of one-way streets, it is best to start the route near the upper end of the street, working down through the looping process.
- 5) The curb side collection system will be used in the four-step design system, and a crew of two in each truck--one driver and one loader.

In addition, the router crew must apply its intelligence, experience, common sense, and certain rules of thumb and as the router gains experience, he will recognize routings that are efficient for certain block patterns and he will be able to modify his routes. Some of these micro routing techniques to be applied in different traffic paths are shown in Figures 3, 4, and 5 (19).

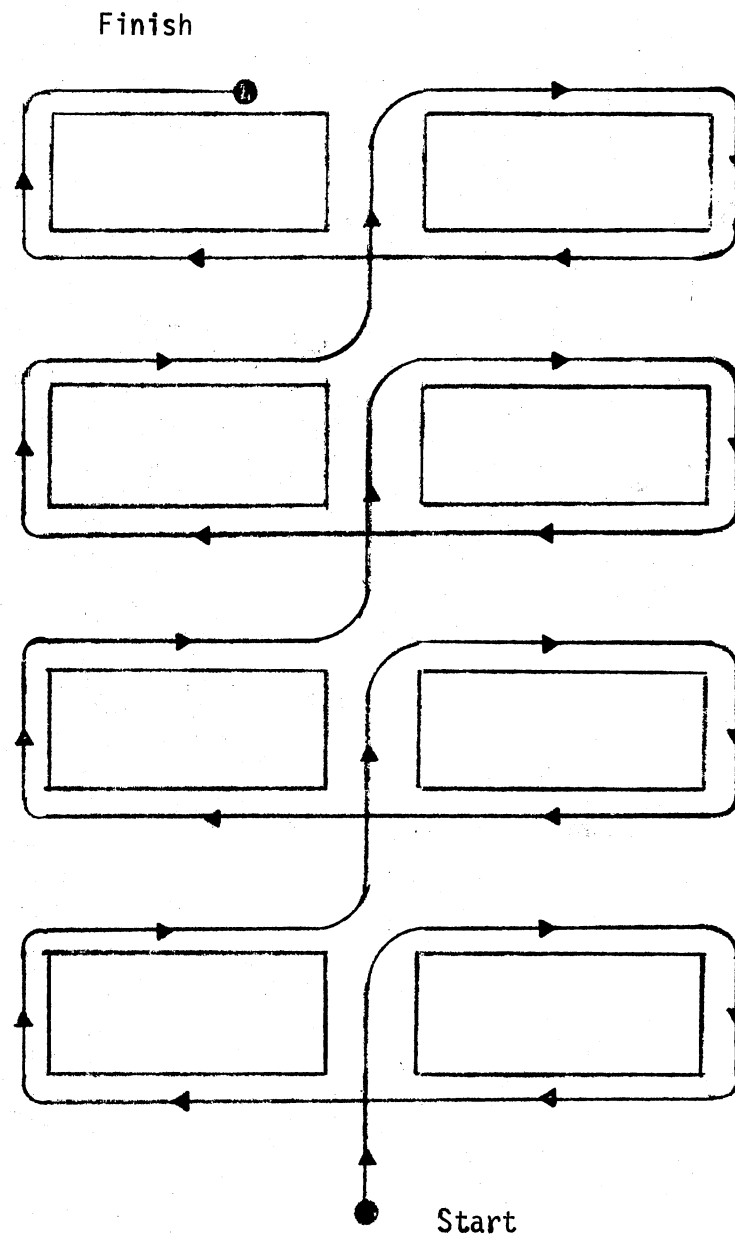


Figure 3. Specific Routing Pattern for One-way Street, One-side-of-the-street Collection. (In this pattern, collection is made from both sides of the one-way street during the pass. For wide or busy one-way streets, it is necessary to loop back to the upper end and make a straight pass down the other side.)

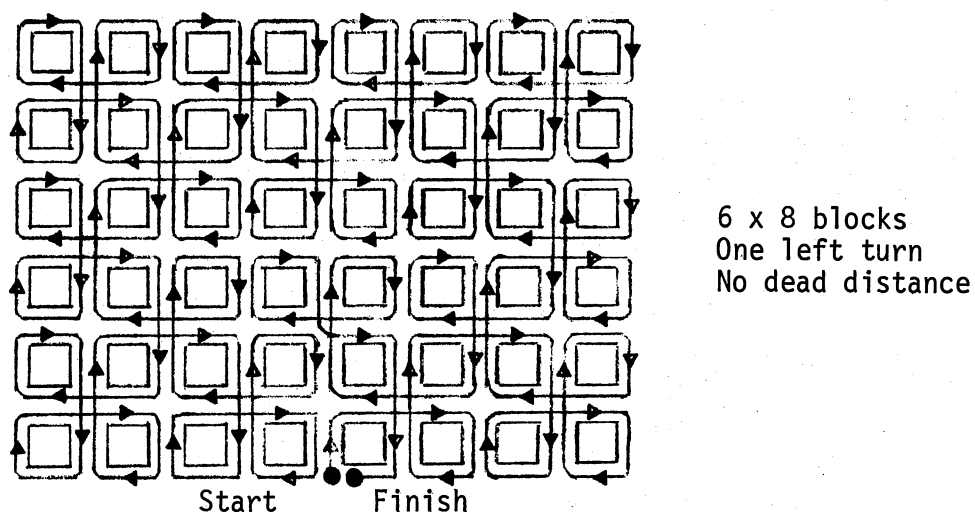
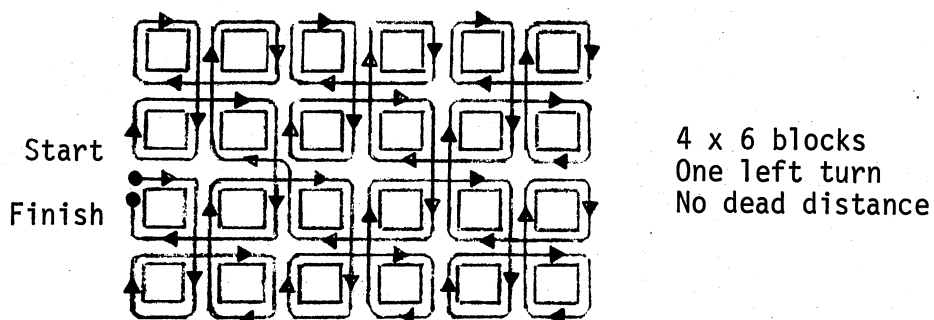
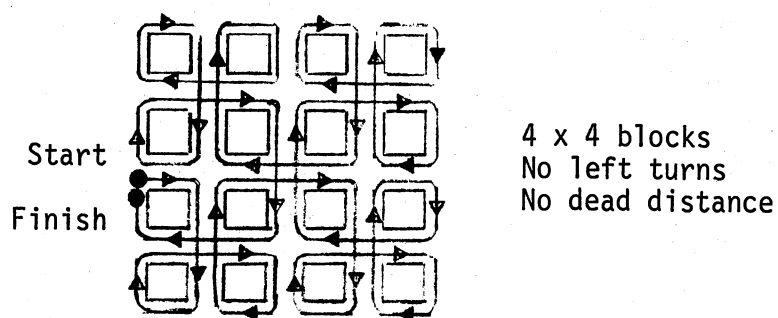
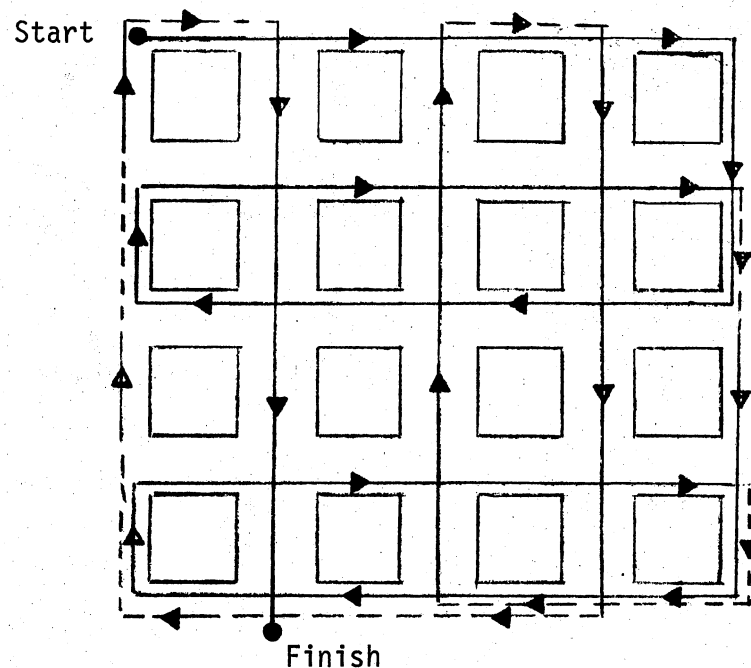
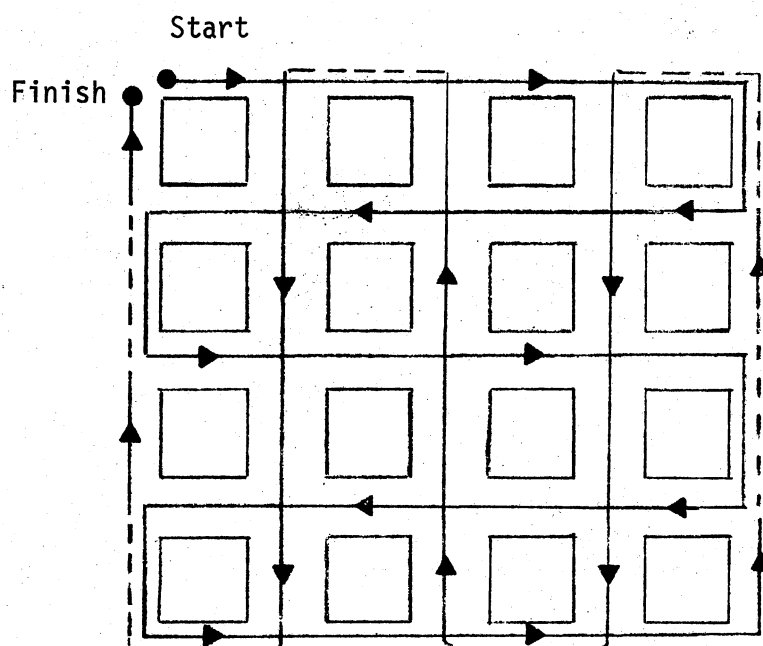


Figure 4. Combinations of Four-block Pattern, One-side-of-the-street Collection. (Note that each route is started midway on an evenly divided side of the grid and uses the same routing pattern, with progression in a counter-clockwise fashion. For the larger grids, once the outside is routed, the inside is routed in a clockwise progression.)



Pattern A



Pattern B

Figure 5. Specific Routing Patterns. (In specific routing patterns for both sides of the street collection, Pattern A entails no left turns, and Pattern B requires nine left turns. Dash lines represent "dead distance," or non-collection segments of the route.)

Step 4. Determine Total Annual Collection Costs

Step 4 determines the total annual cost of the system to be used excluding the landfill cost; hence, the cost of the monthly residential refuse collection and the monthly commercial refuse collection can be determined. This step is important in establishing the efficiency of the system; however, it is flexible and the figures will change with costs. In addition, some of the abstract values from step a to be used in this step should be based upon experience and knowledge, as shown in the following general sub-steps:

Initial Purchase Cost

(number of refuse trucks) x (price of each) \$a

operational equipment costs

(oil, gas, maintenance, etc.)

(number of refuse trucks)(total work hr/yr)(\$ cost/hr) = x

miscellaneous cost = y

b \$b

Personnel Cost

(number of refuse truck drivers)(total work hr/yr)
(cost \$/hr) = W

(number of refuse loaders)(total work hr/yr)
(cost \$/hr) = X

supervision at 10% of (X + X) = Y

fringe benefits at 25% (Social Security, medical) = Z

c \$c

Miscellaneous Expense, Overhead, and Contingency
at 10% of (b + c) \$d

where

number of refuse trucks = from step f
 price of each refuse truck = from step a
 cost/hr including oil, gas, etc., = from step a
 miscellaneous cost = from step a
 number of drivers = from step f
 cost/hr employee = from step a
 number of refuse truck loaders = from step f (one loader per truck)
 supervision and fringe benefits and contingency = an appropriate
 suggested value based upon experience.

Annual Cost

- A. Debt expense (number of years of amortization = L)
 is equal to values in dollars of $\frac{a}{L}$ \$a'
- B. Operational equipment = b
 Personnel cost = c
 Miscellaneous, overhead, and contingency = d
b \$b'
- C. Total refuse cost = (a' + b') \$c'
- D. Annual refuse collection cost for residential only

$$\frac{(C')(Total\ residential\ cu\ yd\ refuse)\ or}{(Total\ residential\ cu\ yd\ refuse)+(Total\ comm.\ refuse\ cu\ yd)}$$

$$(C')(\text{percent of residential refuse generated})$$
 \$d'
- E. Annual residential refuse collection cost per residential
 $d' \div \text{number of residentials}$ \$E'
- F. Debt service reserve (is a figuring of five years amorti-
 zation on all vehicles)

$$\frac{(\text{percent residential refuse generated})(25\%)(a)}{\text{number of residentials}}$$
 \$F'
- G. Monthly residential collection cost $(E' + F') \div 12$ \$G'

D.	Annual refuse collection cost For commercial refuse only (C')(percent of commercial refuse generated)	\$H
E.	Annual commercial refuse collection cost per commercial H ÷ number of commercials	\$I
F.	Department of service reserve $\frac{(\text{percent commercial refuse generated})(25\%)(a)}{\text{number of commercials}}$	\$J
G.	Monthly commercial refuse collection cost (E'' + F'') ÷ 12	\$K

Example

As a model for application of the four-step technique of macro routing for a solid waste collection design, Seminole County, Oklahoma, was selected. This choice was made because of the available data in this county.

It will be shown that the four steps of macro routing are applicable and feasible for solid waste collection. These four steps will be applied step-by-step with illustrations.

Seminole County is situated near the center of Oklahoma, as shown in Figure 6.

Step 1. Determine Characteristics of the Area

Seminole County's population was 28,066 in 1960, and 25,144 in 1970--a decline of 10.4 percent. During the same decade, the population of the United States increased 13.4 percent. The State Employment Security Commission (13) estimates the population of the county will follow this pattern during this decade:

<u>1970</u>	<u>1975</u>	<u>1980</u>
25,144	24,200	23,400

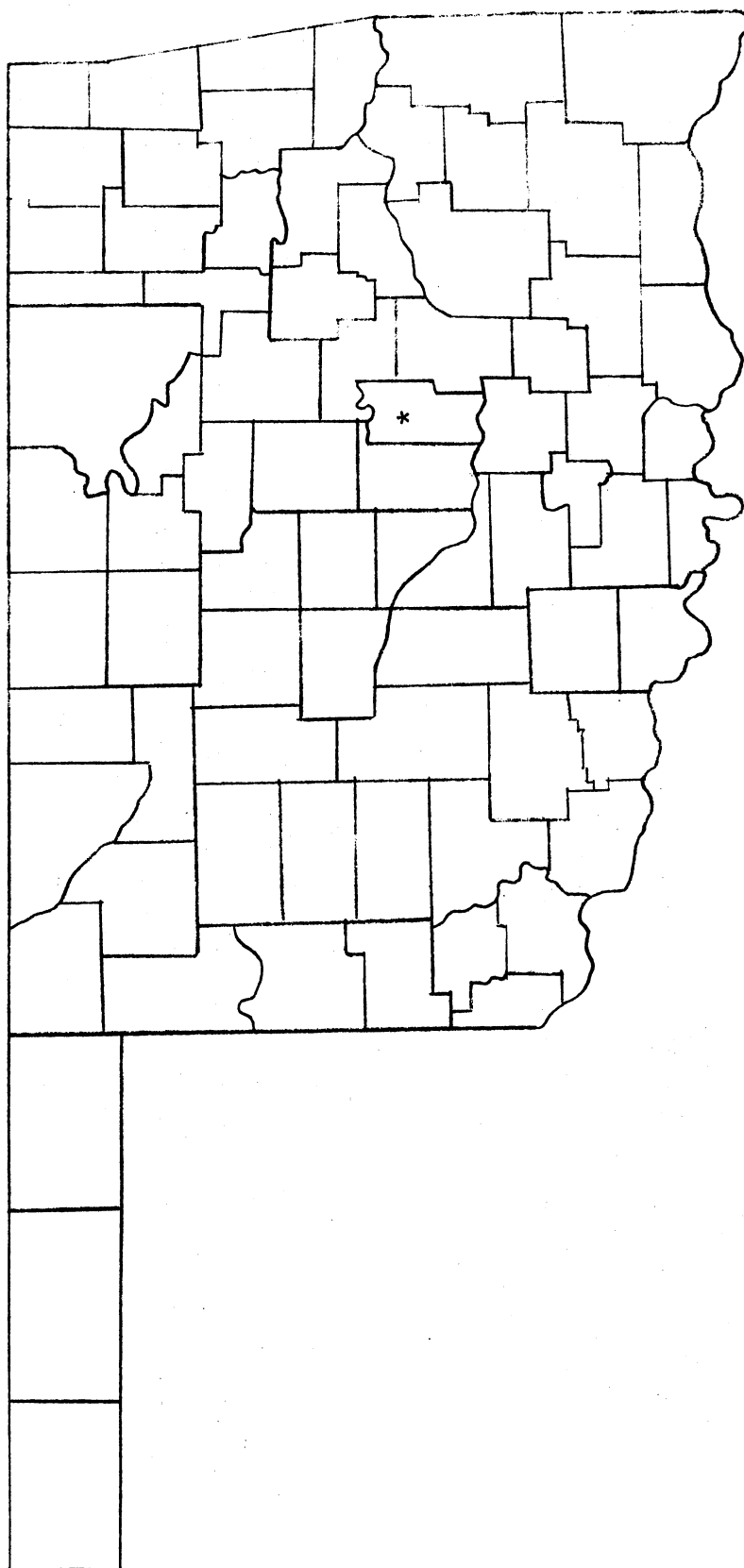


Figure 6. Outline Map of Oklahoma
(* Seminole County)

This projection implies a growth rate of -7 percent compared with a projected increase of 9.4 percent in the population of the state. In 1970, 47.5 percent of the county's population lived in rural areas, compared to 32.0 percent in the state. In the same year, 10 percent lived on farms in rural areas, compared to 7.8 percent in the state.

Table VI shows how employed persons were distributed among occupations in 1970, as compared to employment in the state as a whole.

TABLE VI
MAKEUP OF LABOR FORCE
(percentage in each category)

	County	Oklahoma
Agriculture	14%	-
Domestic services, self-employed, and unpaid family workers	15%	-
Manufacturing	16%	-
Wholesale and retail trade	13%	-
Government	14%	-
All other	28%	-

In addition, there are currently 9,903 housing units in the county. Table VII reveals the condition of housing in the county as measured by recognized indicators of inadequate housing (13), lack of plumbing facilities, and overcrowding.

TABLE VII
HOUSING CONDITIONS

	County	Oklahoma	U. S.
Units lacking some or all plumbing facilities	13%	7.1%	5.9%
Black households lacking some or all plumbing facilities	35%	16.7%	16.8%
Occupied units with 1.0 or more persons per room	8%	7.3%	8.2%
Black households with 1.0 or more persons per room	17%	16.6%	20.0%

According to these standards, there are 1855 housing units in the county which do not enjoy adequate housing conditions. The condition and quality of the present waste collection facilities of Seminole is estimated by the Environmental Health Department, as shown in Table VIII.

TABLE VIII
QUALITY OF PRESENT WASTE COLLECTION FACILITIES

Condition of Facility	% of all County Using This Quality Facility	Average of all Counties in Oklahoma
good	-	0.3
adequate	59.1	38.95
inadequate	4.6	20.88
none, but needed	-	1.76
none needed	-	3.92
using other means of disposal, e.g., septic tanks	36.3	34.19

Environmental health regulations dictate that solid waste must be disposed of in a sanitary landfill rather than through open burning or through simple dumping of solid waste in an open area. Table IX shows the approximate percentage of households in Seminole County which dispose of solid waste in a sanitary landfill, and the percentage which uses an open dump.

TABLE IX
AN APPROXIMATE PERCENTAGE OF HOUSEHOLDS IN SEMINOLE

Condition	Method of Solid Waste Disposal	Average for all Counties in Oklahoma
Percent using sanitary landfill	-	39%
Percent using open dump	23%	29%

Step 2. Locate the Sanitary Landfill Site

The shortest distance between cities in Seminole County is presented in a matrix form as shown in Table X. These values were obtained from the Oklahoma State Department of Highways (14).

TABLE X
SHORTEST DISTANCE BETWEEN CITIES IN SEMINOLE COUNTY
(miles)

	Sasakwa	Wewoka	Cromwell	Konawa	Bowlegs	Seminole	Maud	Lima
Sasakwa	0	14	27	14	21	25	26	18
Wewoka	14	0	13	28	10	12	22	4
Cromwell	27	27	0	45	24	24	34	17
Konawa	14	28	45	0	18	23	12	33
Bowlegs	21	10	24	18	0	5	12	14
Seminole	25	12	24	23	5	0	11	11
Maud	26	22	34	12	12	12	0	22
Lima	18	4	17	33	16	11	22	0

Using the two equations presented previously in the general method for this step, the following consecutive values were found:

Let D = distance in miles (Table X)

C = collections (commercial + residential, Table XI)

Step 2A

1 = Wewoka

2 = Sasakwa

$c_1 = 1961$

$c_2 = 96$

1) $d_1 + d_2 = 14$

2) $c_1 d_1 = c_2 d_2$

Two equations, two unknowns. Hence from equation 1) we derive

$$d_2 = 14 - d_1$$

Replace it with equation 2) and we derive

$$1961 d_1 = 96 (14 - d_1)$$

Therefore

$$d_1 = 1 \text{ mile } (\textcircled{1} \text{ map \#2})$$

Step 2B

$$1 = \text{Wewoka} + \text{Sasakwa}$$

$$2 = \text{Cromwell}$$

$$1) d_1 + d_2 = 14$$

$$2) c_1 d_1 = c_2 d_2$$

$$2057 d_1 = 113 (14 - d_1)$$

$$\therefore d_1 = 1 \text{ mile } (\textcircled{2} \text{ above (1) map \#2})$$

Step 2C

$$1 = \text{Bowlegs}$$

$$2 = \text{Konawa}$$

$$1) d_1 + d_2 = 18$$

$$2) c_1 d_1 = c_2 d_2$$

$$130 d_1 = 609 (18 - d_1)$$

$$\therefore d_1 = 14 \text{ miles } (\textcircled{3} \text{ map \#2})$$

Step 2D

$$1 = \textcircled{2} = \text{Wewoka} + \text{Cromwell} + \text{Sasakwa}$$

$$2 = \textcircled{3} = \text{Konawa} + \text{Bowlegs}$$

$$1) d_1 + d_2 = 14$$

$$2) c_1 d_1 = c_2 d_2$$

$$2170 d_1 = 739 (14 - d_1)$$

$$\therefore d_1 = 4 \text{ miles } (\textcircled{4} \text{ map \#2})$$

Step 2E

1 = ④ = Wewoka + Cromwell + Sasakwa + Konawa + Bowlegs

2 = Maud

$$1) d_1 + d_2 = 19$$

$$2) c_1 d_1 = c_2 d_2$$

$$2909d_1 = 455 (19 - d_1)$$

$$d_1 = 3 \text{ miles (⑤ map \#2)}$$

Step 2F

1 = Seminole

2 = ⑤ W. + C. + S. + K. + B. + M.

$$1) d_1 + d_2 = 10$$

$$2) c_1 d_1 = c_2 d_2$$

$$3279d_1 = 3364 (10 - d_1)$$

$$d_1 = 5 \text{ miles (⑥ map \#2)}$$

Step 2G

1 = ⑥ = W. + C. + S. + K. + B. + M. + S.

2 = Lima

$$1) d_1 + d_2 = 14$$

$$2) c_1 d_1 = c_2 d_2$$

$$6643 d_1 = 65 (14 - d_1)$$

$$\therefore d_1 = 0 \text{ miles (⑦ map \#2)}$$

Calculations show that the landfill is closer to Seminole. Thus, it should be close to Seminole city, as shown in Figure 8. (Note: the landfill is located about 10 miles east of Seminole city).

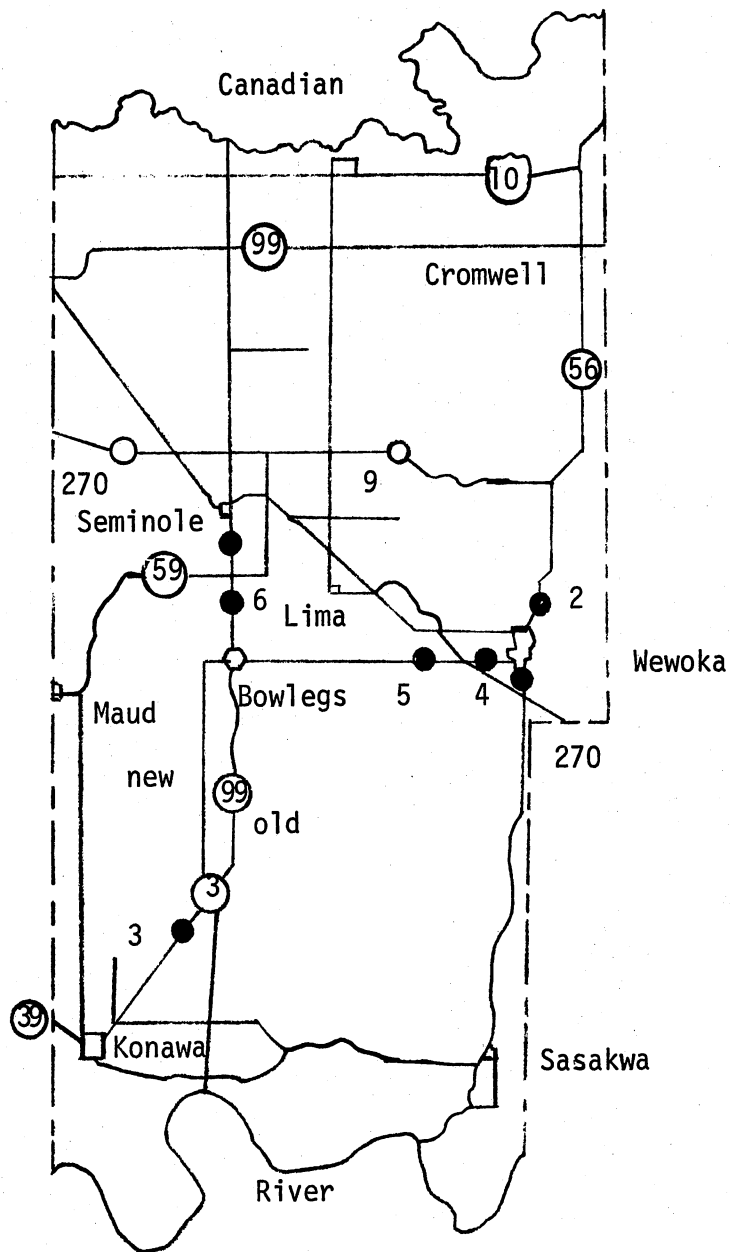


Figure 7. Location of Landfill in Seminole County, Seminole City (● centroid number)

Step 3. Determine the Required Number of Collection Trucks

There are several steps that must be taken to make the determination for the required number of refuse collection trucks. Each of these steps is directly related to the other, as has been explained in the general method of this step. The calculations and the results of each step are explained below.

Establishing Design Values. In this example, most of the values have been selected from previous data obtained for the county and from the data of counties similar to Seminole in relation to social life, population, and condition of housing, etc., showing the following values:

- 1) 236 lbs/business/week (15)
- 2) 3.45 lbs/capita/day refuse (residential and commercial)(15)
- 3) Solid waste will average 500 lbs/cu yd compacted (16)
- 4) Number of residential and commercial refuse collections of each city of Seminole County is listed in Table XI (18)
- 5) Population of each city as listed in Table XI (18)
- 6) 0.4 min/pickup residential and 0.5 min/pickup commercial curb-side collection (16)
- 7) \$12,000 for 14 cu yd truck price and \$10,000 for 12 cu yd truck (estimated)
- 8) \$4.25/hr cost of oil, gas, maintenance (15)
- 9) \$25,000 miscellaneous cost (15)
- 10) \$3.13/hr/employee wage (estimated)
- 11) 10% cost for supervision, 25% as fringe benefits, and 10% for

contingency (estimated)

12) 55 mi/hr average speed limit on highways

13) Total time/day for micro traveling only for residential refuse collection and commercial refuse collection = 3 hr/day and 3/5 hr/day, respectively (estimated).

Determine Solid Waste Generated/day/city. The cubic yd/day of commercial and residential refuse is calculated by using the following formulas (Table XI):

cu yd/day commercial refuse =

$$\frac{(\text{lbs refuse/business week})(\text{number of commercials})}{(7 \text{ days/week})(\text{lbs/cu yd compacted})}$$

e.g.,

$$\text{Wewoka cu yd/day commercial} = \frac{236 \times 194}{7(500)} = 13.1 \text{ (Table XII)}$$

Similarly, the residential cu yd/day refuse is calculated by the following formula:

cu yd/day residential refuse =

$$\frac{(\text{total lbs/capita/day})(\text{population})}{\text{lbs/cu yd compacted}} - (\text{commercial cu yd/day})$$

e.g.,

$$\text{Wewoka cu yd/day residential refuse} = \frac{3.64 \times 5284}{500} - 13.1 = 23.5$$

(Table XI).

TABLE XI
CU YD COMMERCIAL AND RESIDENTIAL REFUSE GENERATION
IN EVERY CITY PER DAY

City	Ref. 18 Residential Collections	Ref. 18 Commercial Collections	Ref. 18 1970 Population	Commercial cu yd/day	Residential* cu yd/day
Wewoka	1,767	194	5,284	13.1	23.5
Sasakwa	86	10	321	0.7	1.5
Bowlegs	126	4	300	0.3	1.8
Maud	419	36	1,143	2.3	5.5
Seminole	2,987	292	7,878	19.7	34.7
Cromwell	105	8	287	0.5	1.4
Lima	65	0	238	0	1.6
Konawa	<u>558</u>	<u>51</u>	<u>1,719</u>	<u>3.4</u>	<u>8.5</u>
Total	6,113	595	17,170	40.0	78.6

*Residential cu yd refuse = total cu yd refuse - commercial cu yd refuse

Residential cu yd refuse = 3.64 - commercial

Place Each City Into One of Three Groups. In order to calculate the number of residential refuse collection stops for each group, the following adjustment was used:

According to the discussion in the general method of this step, the cities of the lowest number of residential refuse collections are Bowlegs, Lima, Cromwell, and Sasakwa (Table XI). Hence, there are 382 total residential refuse collection stops in Group III.

Therefore, the total residential refuse collection stops for each Group I and Group II will be calculated as the following:

$$\frac{\text{total residential refuse collections (Table XI)} - \text{residential refuse collection stops of Group III}}{2}$$

or

$$\frac{5113 - 382}{2} = 2866 \text{ collections}$$

The cities of Groups I and II are placed so that the total residential refuse collection stops approximate the value calculated above. As discussed in the general methods of calculation (step 3), the following groupings were found to be most efficient:

<u>Group I</u>	<u>Group II</u>	<u>Group III</u>
Seminole 2,866	Wewoka 1,767	Bowlegs 126
	Konawa 558	Lima 65
	Maud 419	Cromwell 105
	Seminole 121	Sasaka 86
<u>2,866</u>	<u>2,865</u>	<u>382</u>

Determine the Total cu yd of Residential and Commercial Refuse per Day of Collection. From the previous grouping step, the following tabulations of the quantity of residential and commercial refuse in cu yd/day were made for each group collection schedule, as shown in Tables XII and XIII, respectively.

As shown in Tables XII and XIII, the residential maximum truck capacity required is approximately 78 cu yd and commercial capacity required is approximately 20 cu yd., respectively, except on Saturday when the truck capacity required is approximately 40 cu yd.

TABLE XII
RESIDENTIAL REFUSE GENERATED IN EACH CITY PER COLLECTION DAY

City	cu yd/day residential refuse	Number of Days of Refuse Accumulation				
		4 Mon.	4 Tues.	7 Wed.	3 Thur.	3 Fri.
Wewoka	23.5		94			70.5
Sasawka	1.5			10.5		
Bowlegs	1.8			12.6		
Maud	5.5		22			16.5
Seminole	33.3 1.4	133.2	5.6		99.9	4.2
Cromwell	1.4			9.8		
Lima	1.6			11.2		
Konawa	<u>8.5</u>		<u>34</u>			<u>25.5</u>
Total	78.5	133.2	155.6	44.1	99.9	116.7
Capacity needed - two trips to landfill		66.6	77.8	22.1	50	58.4

These values have been calculated as the following example:

Wewoka = $23.5 \times 4 = 94$ cu yd residential refuse
 Sasakwa = $1.5 \times 7 = 10.5$ cu yd residential refuse

TABLE XIII
COMMERCIAL REFUSE GENERATION FOR EACH CITY PER DAY OF COLLECTION

City	cu yd/day Commercial Refuse	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.*
Wewoka	13.1	13.1	13.1	13.1	13.1	13.1	26.2
Sasakwa	0.7	0.7	0.7	0.7	0.7	0.7	1.4
Bowlegs	0.3	0.3	0.3	0.3	0.3	0.3	0.6
Maud	2.3	2.3	2.3	2.3	2.3	2.3	4.6
Seminole	19.7	19.7	19.7	19.7	19.7	19.7	39.4
Cromwell	0.5	0.5	0.5	0.5	0.5	0.5	1.0
Lima	0	0	0	0	0	0	0
Konawa	<u>3.4</u>	<u>3.4</u>	<u>3.4</u>	<u>3.4</u>	<u>3.4</u>	<u>3.4</u>	<u>6.8</u>
Total	40.0	40.0	40.0	40.0	40.0	40.0	80.0
Required truck capacity based on two trips/day to landfill							
	20	20	20	20	20	20	40

*The commercial cu yd refuse is multiplied by two because it is an evening collection

Determine the Number of Collection Stops Made by Different-sized Refuse Trucks. The number of stops made by the different-sized trucks for each day of residential and commercial refuse collection was determined to be as follows:

Monday

$133.2 \text{ cu yd (Table XII)} \div 2866 \text{ (Table XI)} = 0.046 \text{ cu yd/collection stop.}$

Truck Size	Collection Stops
------------	------------------

30 ÷ 0.046 = 645 two trips to landfill/day = 1290

20 ÷ " = 430	"	= 860	"
--------------	---	-------	---

18 ÷ " = 387	"	= 774	"
--------------	---	-------	---

14 ÷ " = 301	"	= 602	"
--------------	---	-------	---

12 ÷ " = 258	"	= 516	"
--------------	---	-------	---

Tuesday

155.6 cu yd (Table XII) ÷ 2865 (Table XI) = 0.054 cu yd

Truck Size	Collection Stops
------------	------------------

30 ÷ 0.054 = 552 two trips to landfill/day = 1104 "

20 ÷ " = 368	"	= 736	"
--------------	---	-------	---

18 ÷ " = 331	"	= 662	"
--------------	---	-------	---

16 ÷ " = 295	"	= 590	"
--------------	---	-------	---

14 ÷ " = 258	"	= 516	
--------------	---	-------	--

12 ÷ " = 221	"	= 442	"
--------------	---	-------	---

Wednesday

44.1 cu yd (Table XII) ÷ 382 collections (Table XI) = 0.115 cu yd

Truck Size	Collection Stops
------------	------------------

30 ÷ 0.115 = 260 two trips to landfill/day = 520 "

20 ÷ " = 173	"	= 346	"
--------------	---	-------	---

18 ÷ " = 156	"	= 312	"
--------------	---	-------	---

16 ÷ " = 139	"	= 278	"
--------------	---	-------	---

14 ÷ " = 121	"	= 242	"
--------------	---	-------	---

12 ÷ " = 104	"	= 208	"
--------------	---	-------	---

Thursday

99.9 cu yd (Table XII) ÷ 2866 collections (Table XI) = 0.035 cu yd

Truck Size	Collection Stops
------------	------------------

30 ÷ 0.035 = 860 two trips to landfill/day = 1720	"
---	---

20 ÷ " = 573	" = 1146
--------------	----------

18 ÷ " = 516	" = 1032
--------------	----------

16 ÷ " = 458	" = 916
--------------	---------

14 ÷ " = 401	" = 802
--------------	---------

12 ÷ " = 344	" = 688
--------------	---------

Friday

116.7 cu yd (Table XII) ÷ 286 collections (Table XI) = 0.04 cu yd

Truck Size	Collection Stops
------------	------------------

30 ÷ 0.041 = 737 two trips to landfill/day = 1474	"
---	---

20 ÷ " = 491	" = 982
--------------	---------

18 ÷ " = 442	" = 884
--------------	---------

16 ÷ " = 393	" = 788
--------------	---------

14 ÷ " = 344	" = 688
--------------	---------

12 ÷ " = 295	" = 590
--------------	---------

Every Day Commercial Refuse Collection Excluding Saturday

40 cu yd (Table XIII) ÷ 9 collections (Table XI) = 0.067 cu yd

Truck Size	Collection Stops
------------	------------------

30 ÷ 0.067 = 446 two trips to landfill/day = 892	"
--	---

20 ÷ " = 298	" = 596
--------------	---------

18 ÷ " = 268	" = 536
--------------	---------

16 ÷ " = 238	" = 476
--------------	---------

14 ÷ " = 208	" = 416
--------------	---------

$$12 \div " = 208 \quad " = 358 \quad "$$

Saturday Commercial Refuse Collection

$$80 \text{ cu yd (Table XIII)} \div 595 \text{ (Table XI)} = 0.135 \text{ cu yd}$$

Truck Size	Collection Stops
$30 \div 0.135 = 223$ two trips to landfill/day	$= 446$ "
$20 \div " = 149$	$= 298$ "
$18 \div " = 134$	$= 268$ "
$16 \div " = 119$	$= 238$ "
$14 \div " = 104$	$= 208$ "
$12 \div " = 89$	$= 178$ "

Determine the Number of Refuse Collection Trucks and the Macro

Routing for Each Truck per Day of Refuse Collection. From the discussion of the general method of this step, the following combination of trucks was found to be the most feasible:

For residential refuse trucks, combination of

4 trucks x 14 cu yd capacity

2 trucks x 12 cu yd capacity.

For commercial refuse trucks, combination of

3 trucks x 12 cu yd capacity.

This combination has been chosen by satisfying the total cu yd of residential refuse truck capacity required on Monday or Tuesday, 77.8 cu yd (Table XII). Similarly, the three trucks of 12 cu yd capacity will be adequate in size for commercial refuse collection except on Saturday (Table XIII). Also, the residential refuse trucks have been chosen by satisfying the number of collection stops made by this size truck on Monday and Tuesday (step e) and the total time of collection

stops available in Table XIV. Similarly, the commercial refuse trucks have been chosen by satisfying the number of everyday collection stops made by this size truck on every day (step e commercial) and the time available for collection stops from Table XIV.

These combinations of residential and commercial refuse trucks have been chosen on the basis of using their full load as much as possible before going to the landfill. However, different combinations of refuse trucks will satisfy the total capacity of cu yd of refuse generated per day of refuse collection, and it will probably satisfy the total number of collection stops, but will not be feasible because there will not be enough time for each truck to fill the truck before the end of the working day.

By using Tables XI, XII, and XIII, and Figure 8, with the macro routing technique which has been previously described in the general method for this step, the following truck routings were obtained. These routes were adjusted to minimize traveling and maximize refuse collection times.

Monday

	285	285
Truck #1 - 14 cu yd:	landfill - Seminole - landfill - Seminole -	
	landfill	
	285	285
Truck #2 - 14 cu yd:	landfill - Seminole - Landfill - Seminole -	
	landfill	
	285	285
Truck #3 - 14 cu yd:	landfill - Seminole - landfill - Seminole -	
	landfill	
	285	285
Truck #4 - 14 cu yd:	landfill - Seminole - landfill - Seminole -	
	landfill	

Truck #5 - 12 cu yd: landfill - ²⁸⁵Seminole - landfill - ²⁸⁵Seminole - landfill

Truck #6 - 12 cu yd: landfill - ⁷⁰Seminole - can be used for special collections, such as for debris, for six hours

Tuesday

Truck #1 - 14 cu yd: landfill - ²⁵⁸Wewoka - landfill - ²⁵⁸Wewoka - landfill

Truck #2 - 14 cu yd: landfill - ²⁵⁸Wewoka - landfill - ²⁵⁸Wewoka - landfill

Truck #3 - 14 cu yd: landfill - ²⁵⁸Wewoka - landfill - ²⁵⁸Wewoka - landfill

Truck #4 - 14 cu yd: landfill - ²¹⁹Wewoka - ³⁹Seminole - landfill - ¹⁷⁶Maud - ⁸²Seminole - landfill

Truck #5 - 12 cu yd: landfill - ²¹²Konawa - landfill - ²¹²Konawa - landfill

Truck #6 - 12 cu yd: landfill - ¹³³Konawa - ⁷⁹Maud - landfill - ¹⁶⁴Maud - this truck can be used for three hours for special collections, such as for debris

Wednesday

Truck #1 - 14 cu yd: landfill - ⁸⁶Sasakwa - ³⁵Lima - landfill - ¹⁰⁵Cromwell - ¹⁶Lima - landfill

Truck #2 - 12 cu yd: landfill - ¹⁰⁴Bowlegs - landfill - ²²Bowlegs - ¹⁴Lima - landfill

Truck #3 - 14 cu yd: this truck can be used for special collections for the whole day

Truck #4 - 14 cu yd: off)
 Truck #5 - 14 cu yd: off) These trucks can be used for replace-
 Truck #6 - 12 cu yd: off) ment or maintenance

Thursday

The same routes assigned as on Monday.

Friday

The same routes assigned as on Tuesday.

Saturday Commercial Refuse Collection

The three groups that have been retired on Wednesday residential refuse collection will be assigned to work on Saturday commercial refuse collection on the evening shift. Routing will be in the following manner:

Truck #1 - 14 cu yd:	landfill - Seminole - landfill - Seminole
	104 104
	51 36 4
Truck #2 - 14 cu yd:	landfill - Konawa - Maud - Bowlegs -
	10 84
	landfill - Cromwell - Seminole - landfill
	104 10
Truck #3 - 14 cu yd:	landfill - Wewoka - landfill - Sasakwa -
	90
	Wewoka - landfill

Every Day Commercial Refuse Routings

Truck #1 - 12 cu yd:	landfill - Seminole - landfill - Seminole -
	landfill
	179 113
Truck #2 - 12 cu yd:	landfill - Konawa - Maud - Bowlegs -
	5 36 4
	10 132
	landfill - Sasakwa - Wewoka - landfill
	8 62
Truck #3 - 12 cu yd:	landfill - Cromwell - Wewoka - This truck
	can be used for 2.5 hours for special col-
	lections or maintenance or replacement.

The results of the whole adjustment of this step are tabulated as shown in Table XIV. The total time of each truck spent during a work day excluding the micro traveling time is calculated on the following basis:

- 1) an average speed on the highway of 55 mi/hr
- 2) half-hour total break per day at the landfill
- 3) landfill is about 10 miles east of Seminole City
- 4) 0.5 minutes per commercial refuse collection stop
- 5) 0.4 minutes per residential refuse collection stop
- 6) three-hours per day for residential refuse collection micro traveling time excluding collection stops - time suggestion in step g
- 7) three and one-half hours per day for commercial refuse collection micro traveling. Time excluding collection stops. Time suggestion to follow step g.

The total time of pickup collections is calculated as follows:

Total time of work excluding micro traveling time = $8 - 3 = 5$ hours.

Hence,

$5 \text{ hr} = (\text{time of breaks}) + (\text{macro traveling time}) + (\text{total pickup time})$

$5 \text{ hr} = 0.5 \text{ hr} + (\text{miles of traveling} \div 55) + (X)$.

By following the macro route of each truck, the distance will be known from Table X, e.g.,

Wednesday truck #1 residential total traveling miles - 106 mi \div 55 mi/hr = 1.93 hr. Hence,

$1.93 \text{ hr} + 0.5 \text{ hr breaks} + (X) = 5$, or $X = 5 - 2.43 = 2.57 \text{ hr}$ for collection pickups. Therefore, the number of collection stops that truck #1 can make per day =

TABLE XIV
TOTAL TIME OF PICKUPS (COLLECTIONS) AND THE NUMBER
OF COLLECTION STOPS PER DAY

Day	Truck Size	Macro Trav. Total Mi.	Macro Trav. Total Hrs.	Total Break Time /Day	Total Time Pickup Collec-tions	Total Time/Day Excluding Micro Trav. Time	Number Collection Stops/Day
Monday	14	-	0.7	0.5	3.8	5	570
	14	-	0.7	0.5	3.8	5	570
	14	-	0.7	0.5	3.8	5	570
	14	-	0.7	0.5	3.8	5	570
	12	-	0.7	0.5	3.8	5	516
	12	-	0.7	0.5	3.8	5	70
Tuesday	14	48	0.87	0.5	3.63	5	516
	14	48	0.87	0.5	3.63	5	516
	14	48	0.87	0.5	3.63	5	516
	14	46	1.02	0.5	3.48	5	516
	12	92	1.67	0.5	2.83	5	425
	12	59	1.07	0.5	3.43	5	376
Wed'day	14	106	1.93	0.5	2.57	5	242
	12	29	0.53	0.5	3.97	5	140
Thursday	(same as Monday)						
Friday	(same as Tuesday)						
Every day							
Commer-cial	12	-	0.7	0.5	3.3	4.5	292
	12	103	1.87	0.5	2.37	4.5	233
	12	63	1.15	0.5	2.85	4.5	70
Saturday	14	-	0.7	0.5	3.3	4.5	208
	14	100	1.82	0.5	2.0	4.5	185
	14	101	1.84	0.5	2.16	4.5	204

$$N \text{ stops} \times \frac{0.4 \text{ min/stop}}{60 \text{ min/hr}} = 2.57 \text{ hr}$$

Hence, $N \text{ stops} = 386 \text{ stops}$, but on Wednesday (from step 3), truck #4 can hold only 242. Therefore, 242 is the total number of collection stops that truck #1 (14 cu yd) can make per day on Wednesday based upon two trips to the landfill. Similarly, the values of every truck of every day is calculated as shown in the procedure in Table XIV.

Step 4. Determine Total Annual Costs

From the cost values presented in step a outlined in step 4 of the general method, the following values were determined:

A. Initial purchase cost

4 - 14 cu yd packer trucks at \$12,000	\$48,000	
5 - 12 cu yd packer trucks at \$10,000	<u>50,000</u>	\$98,000

B. Operational equipment cost - oil, gas maintenance, etc.

9 packer trucks - 18,720 hrs/yr at \$4.25/hr	79,560	
Miscellaneous	<u>25,000</u>	104,560

C. Personnel cost

9 drivers - 18,720 hrs/yr at \$3.13/hr	58,594	
9 loaders (1/truck), 18,720 hrs at \$3.13/hr	58,594	
Supervision at 10%	11,719	
Fringe benefits at 25%	<u>29,297</u>	158,204

D. Miscellaneous expense, overhead, and contingency at 10% (of B + C)

<u>26,276</u>	26,276
---------------	--------

Annual cost

A. Debt expense (5-yr amortization) $\frac{A}{5}$	<u>19,600</u>	19,600
B. Operational equipment (B)	104,560	
Personnel cost (C)	158,204	
Miscellaneous, overhead, and contingency	<u>26,276</u>	289,040
C. Total annual cost		\$308,640

D. Annual collection cost for residential only \$308,640 x 0.663	204,628
E. Annual residential collection cost/d.u. \$204,628 ÷ 5113	33
*F. Debt, service reserve (0.663 x 25% x 98000 ÷ 6113)	2.66
G. Monthly residential collection cost (E + *F) ÷ 12	<u>3.00</u>
D. Annual collection cost for commercial only \$308,640 x 0.337	104,012
E. Annual commercial collection cost/d.u. \$104,012 ÷ 595	175
F. Debt, service reserve (0.337 x 25% x 9800 ÷ 595)	13
G. Monthly commercial collection cost (E + F) ÷ 12	<u>15</u>

*F = debt service reserve in figuring a five-year
amortization on all vehicles.

CHAPTER IV

DISCUSSION

Emphasis of this investigation was on developing an efficient method and a feasible solution for refuse collection problems. An analytical process of determining the minimum number of trucks and optimum number of services that constitute a fair day's work was desired. A fair day's work was determined and routes were balanced by analysis of each component of time in the routing day, e.g., how the crew spends its time including traveling, breaks, disposal, pickup, and micro routing. Adding these components, times of collection day result in step f, Table XIV. However, the parameters in most of step 3 are in close agreement with those of Ralph Stone (2). Stone found that 0.2 to 0.4 minutes were required for a single residential curbside collection of two cans of refuse for one loader man. A comparison of the results of step 4 with similar work previously done by Stone (2) and Golueke (22) shows that the 4-step technique for macro routing is economically feasible. It was found that costs for individual residential service (monthly rate) as calculated by Stone and Golueke was in close agreement with the \$3.00 cost calculated by the 4-step method. Since increased interest rates and inflation have drastically increased costs since the date of the previous studies (1960, 1970), it can be safely assumed that the 4-step method is more economically desirable and the quality of the 4-step method system is more desirable due to the high

frequency of refuse collection per week. The approximate cost of \$3 for monthly residential refuse collection and \$15 for monthly commercial collection appears to be reasonably justifiable in light of the present investigation.

The most obvious results obtained from this investigation were that the total number of trucks was reduced from 12 trucks to a total of nine trucks by using the trucks and the crews that were retired on Wednesday and work commercial refused collection on Saturday. Also, the total number of trucks could be reduced to a total of six trucks by making the every day commercial refuse collection an evening collection and using the same residential refuse trucks, but new crews. The commercial refuse every day macro routing will be the same as assigned in step 3, but on Monday will be the same macro routing as assigned in step 3 for Saturday's group. Also from step 3 (Table XIV), the macro routing schedule of every truck indicates that almost every day there is some time left for truck #6 on Monday, Tuesday, Thursday, and Friday to be used for working purposes or maintenance, special collections, or assisting other trucks in their assigned routes. Truck #3 (14 cu yd) on Wednesday is used all day for debris or special refuse collection for the whole county.

For the every day commercial refuse collection, truck #3 (12 cu yd) has nearly 2.5 hours left which can be used for other purposes such as cleaning, maintenance, etc. Similarly, truck #2 (14 cu yd) on Saturday has nearly 1.5 hr left, which can be used for other purposes.

The same design parameters were used in formulas developed by Colonna and McLaren (17) as were used in the 4-step method in order to determine the total number of trucks required. On the basis of vehicle

capacity (14 cu yd) and residential refuse generation rate at 45 lb/home/wk and a twice per week collection frequency, approximately eight 14 cu yd trucks were required to serve the Seminole County residential area and provide the same quality of services as provided by the six trucks (four 14 cu yd and two 12 cu yd) for residential refuse collection in the 4-step technique. Besides, three of these trucks will be used for commercial refuse collection on Saturday.

The 4-step technique for macro routing design proved to be more economically desirable when compared to similar studies (2)(22)(17). In addition, the method provides a great deal of flexibility, since it can be applied on either a city or county basis and is applicable to many types of refuse collection situations.

CHAPTER V

CONCLUSIONS

The following conclusions are based on the example set forth in the foregoing chapters:

- 1) The 4-step method for solid waste collection design is an efficient empirical method that can be applied for any refuse collection design, and is adaptable for counties as well as for cities.
- 2) This heuristic combination of days of refuse collection for the trucks proved to be feasible in minimizing the number of trucks and maximizing their beneficial use.
- 3) Adjusting the cities into three groups based upon their refuse collection stops was the key for attaining economical feasibility.
- 4) The smaller-sized trucks were shown to be more efficient for solid waste collection in this study.
- 5) This 4-step design does not give the same efficiency for solid waste collection if different combinations of days of refuse collection than those outlined in the procedure discussed in Chapter III are used.

CHAPTER VI

SUGGESTIONS FOR FUTURE WORK

The following are suggestions for future work:

- 1) An intensive design study is suggested on the pipeline system for collecting solid waste under pressure, especially in very highly industrialized cities.
- 2) Determine the analytical effect of the mixed system solid waste collection and street cleaning upon the efficiency and the feasibility of the system.
- 3) To spur the use of updated technology in solid waste systems including methods and equipment.
- 4) Determine the effect of holidays upon solid waste routing systems.
- 5) Charging commercials by the cu yds they generate individually.
- 6) Study of the effect of small refuse transfer stations upon the efficiency and the feasibility of the system applied herein in the 4-step method.

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Personal Data: Born in Beirut, Lebanon, April 18, 1948, the son of Nabiha Habib and Najib Azar. Single. Two sisters, Jackline and Gladiss, and two brothers, Elias and George.

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